Development of Computer-Aided Face-Fit Evaluation Methods

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Project Goals (2001-)

- Develop a new anthropometric database detailing the face-size distribution of respirator users
- Develop new respirator fit test panels for incorporation into national and international standards
- Develop a series of headforms to be incorporated into standards and aid respirator design
- Develop and validate a predictive respirator fit model

Stakeholders/Partnerships

- Occupational Safety and Health Administration
- Respirator wearers
- Respirator manufacturers
- Mine Safety and Health Administration
- Standards Development Organizations

Project History (2001-2009)

- In 2003, the heads and faces of 3997 subjects (respirator users) were measured and 1039 of those were scanned in a large-scale US anthropometric survey[1]
- The Los Alamos National Laboratory (LANL) full-facepiece panel excluded > 15% of the current US workforce[2]
- Face length and face width were determined to be appropriate dimensions for the development of respirator fit test panels[3]
- NIOSH bivariate and principal component analysis (PCA) fit test panels were developed using the survey data and cover > 95% of the current U.S. work force[4]
- Institute of Medicine reviewed the study "Head-and-Face Anthropometric Survey of U.S. Respirator Users" and found that the NIOSH respirator fit test panels represent a clear improvement over the anthropometric data and corresponding LANL panels
- A significant correlation was found between respirator fit and the new NIOSH bivariate fit test panel cells[5]
- The NIOSH panels were found to be appropriate for international consensus standards[6,7]
- Using the anthropometric survey data, a series of headforms representative of current U.S. work force were developed[8]
- Further analysis of the survey data indicated that race/ethnicity is second to gender for impacting face size and shape characteristics[9]
- GM analysis of 26 3-D landmark coordinates confirmed previous PCA of 10 linear landmark dimensions revealing that PC1 accounts for overall face size and PC2 accounts for the width of individual faces[10]

Current Research (2010-)

- Conduct GM analyses using 3-D coordinates for all landmarks (Figure 1)
- Process, analyse and visualize the statistical human shape variability of the current U.S. worker population
- Investigate the correlation between respirator fit and principal component scores based on shape-coordinates
- Determine the if there is any correlation between respirator fit and facial tissue compression using the state-of-the-art technologies (Figures 2 and 3)
- Develop and validate a predictive respirator fit model using five NIOSH headforms

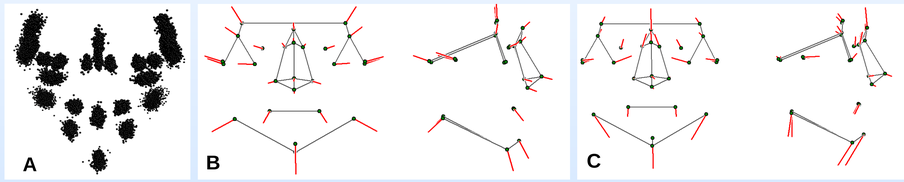

Figure 1. Coordinate location of the 3-D landmarks used to conduct the GM analysis of the human face (A). The red lines indicate how the spatial coordinates change as PC1 increases (B) and as PC2 increases (C).

Figure 2. The anthropometrics laboratory 3-D image capturing capabilities have been improved with the acquisition of a 3dMDcranial™ 5 System. Previous heads were captured with Cyberware Rapid 3-D Digitizer (left) and the new system has higher resolution and a faster capture speed (right).

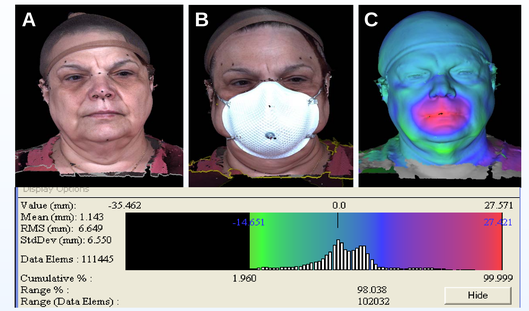

Figure 3. A 3-D image (baseline) of a human subject is captured using the 3dMD digital camera system (A). A second image of the same subject is captured after donning of an N95 respirator (B). The two images were registered and the color histogram depicts surface tissue deformation pre and post donning (C). Green indicates surface depression due to the pressure of the respirator, blue is no change in tissue depth, and red indicates surfaces above the baseline position.

Completed Outcomes

- Results from the research have impacted several national/international respirator standards: NIOSH CBRN standards and ISO/TS 16976-2 Human factors – Part 2 Anthropometrics
- The Food and Drug Administration (FDA) issued a guidance document which requires the use of the NIOSH bivariate panel
- Respirator manufacturers have used the results in designing and sizing new respirator facepieces

Outputs

1. Zhuang Z and Bradtmiller B [2005]. Head-and-Face Anthropometric Survey of U.S. Respirator Users. J. Occup and Environ Hyg, 2, 567-577.
2. Zhuang Z., Guan J, Hsiao H, and Bradtmiller B [2004]. Evaluating the Representativeness of the LANL Respirator Fit Test Panels for the Current U.S. Civilian Workers. JISRP, 21 (III-IV):83-93.
3. Zhuang et al. [2005]. The effect of subject characteristics and respirator features on respirator fit. J. Occup and Environ Hyg. 2, 641-649.
4. Zhuang et al. [2007]. New Respirator Fit Test Panels Representing the Current U.S. Civilian Work Force. J. Occup and Environ. Hyg. 4, 647-659.
5. Zhuang et al. [2008]. Correlation between Respirator Fit and Respirator Fit Test Panel Cells by Respirator Size. Journal of Occupational and Environmental Hygiene 5: 617-628.
6. Du et al [2008]. Head-and-Face anthropometric survey of Chinese workers. Ann. Occup. Hyg., 52: 773-782.
7. Chen et al. [2009]. New respirator fit test panels representing the current Chinese civilian workforce. Ann. Occup. Hyg.,53:297-305.
8. Zhuang et al. Digital 3-D headforms with facial features representative of the current U.S. workforce. Ergonomics, [in press].
9. Zhuang et al. Facial Anthropometric Differences among Gender, Ethnicity, and Age Groups. Ann. Occup. Hyg., [in press].
10. Zhuang et al. Shape analysis of 3-D head scan data for U.S. respirator users. EURASIP Journal on Advances in Signal Processing, [in press].

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